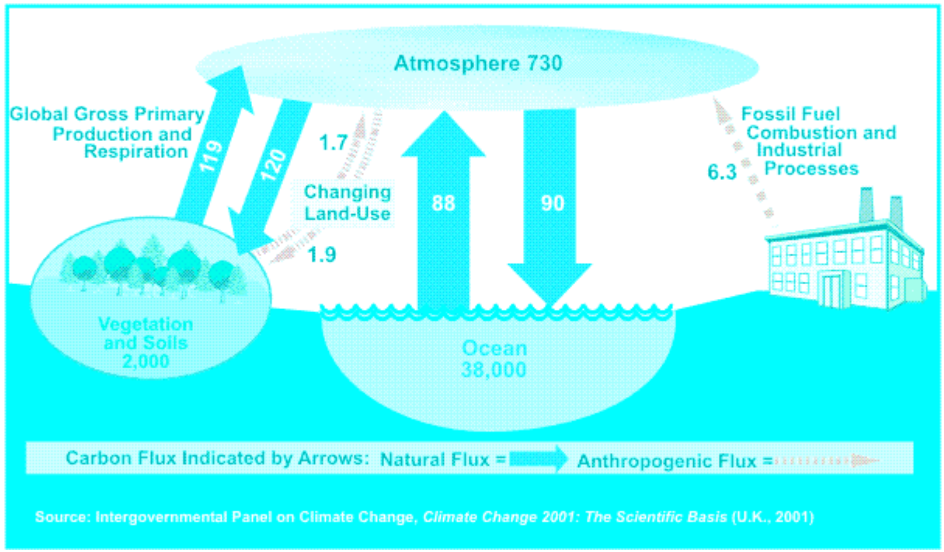
AIRS CO_2 data assimilation with Ensemble Kalman filter: preliminary results



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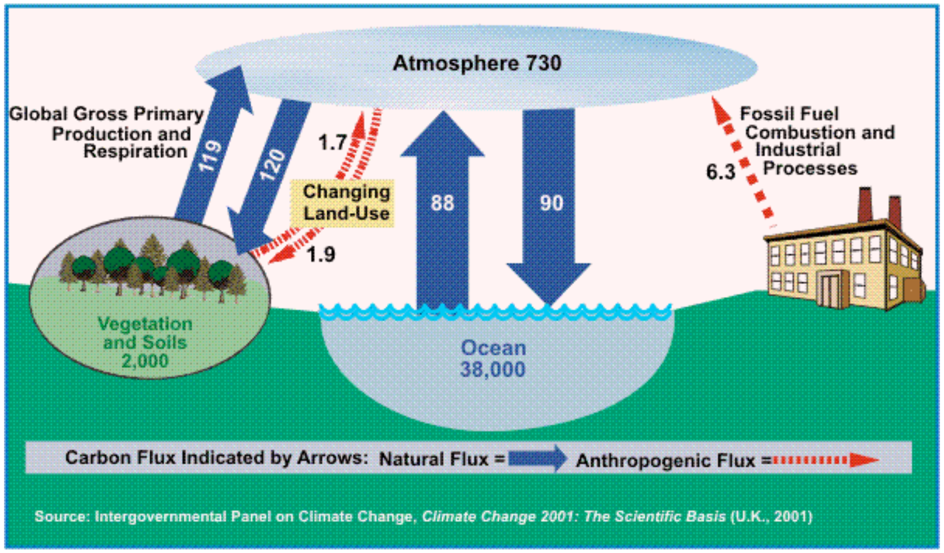
Many thanks to Edward Olsen and Moustafa Chahine for kindly providing us their AIRS L2 CO_2 retrievals and guidance! Other collaborators include Yu-Heng Tseng, Michael Wehner and Masao Kanamitsu.

AIRS CO_2 data assimilation with Ensemble Kalman filter: preliminary results



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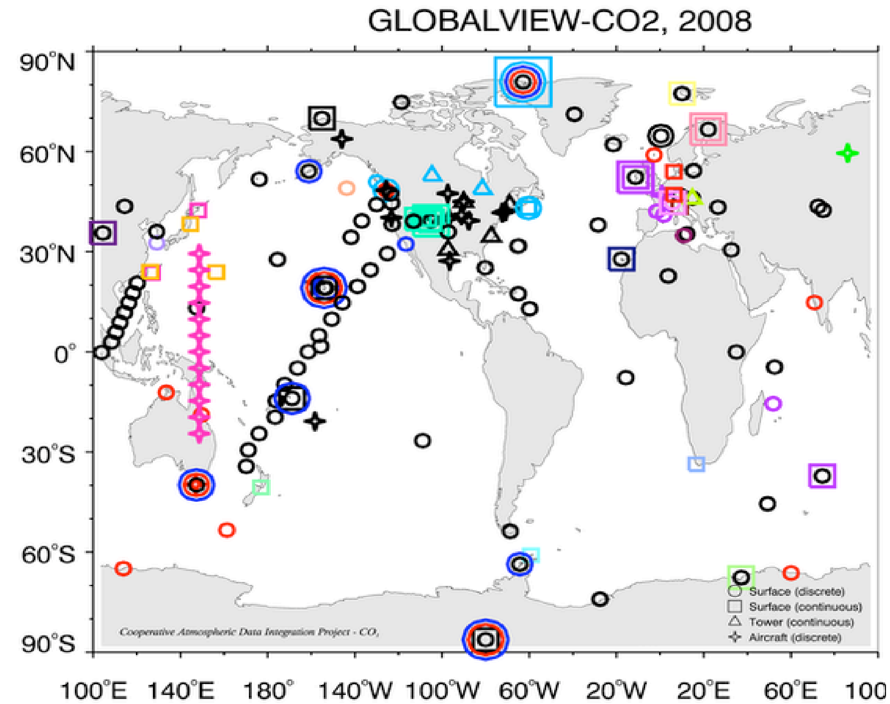
Motivation & Goals

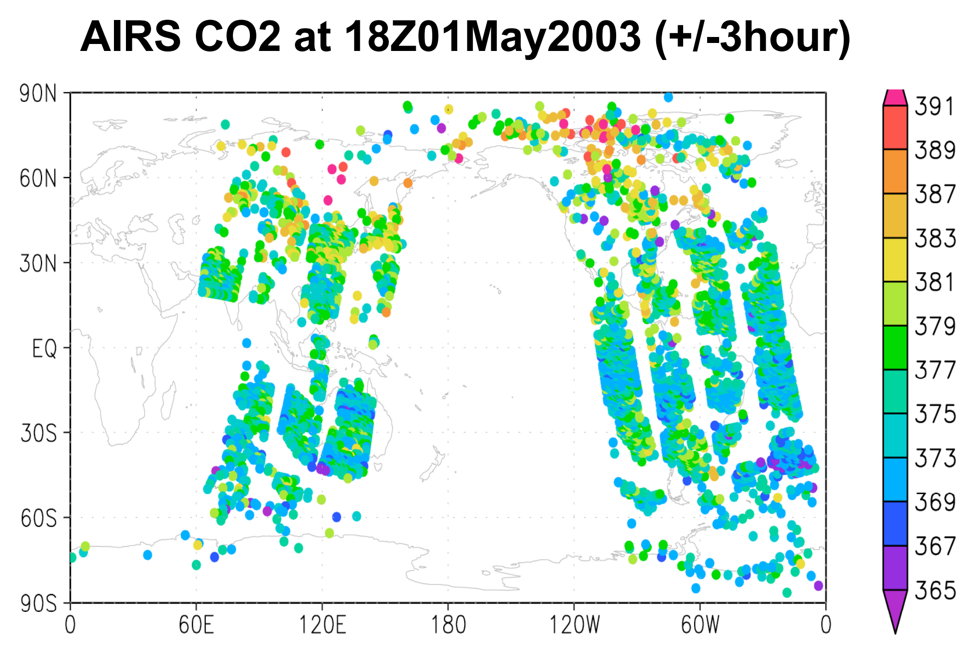
Motivation:

Accurate carbon flux estimation from inversion needs far more CO_2 observations than current surface obs can provide.

Goals:

1. Generate global CO_2 map every 6-hour; start with AIRS, then GoSat
2. Propagate AIRS CO_2 in both horizontal and vertical direction through data assimilation and transport model





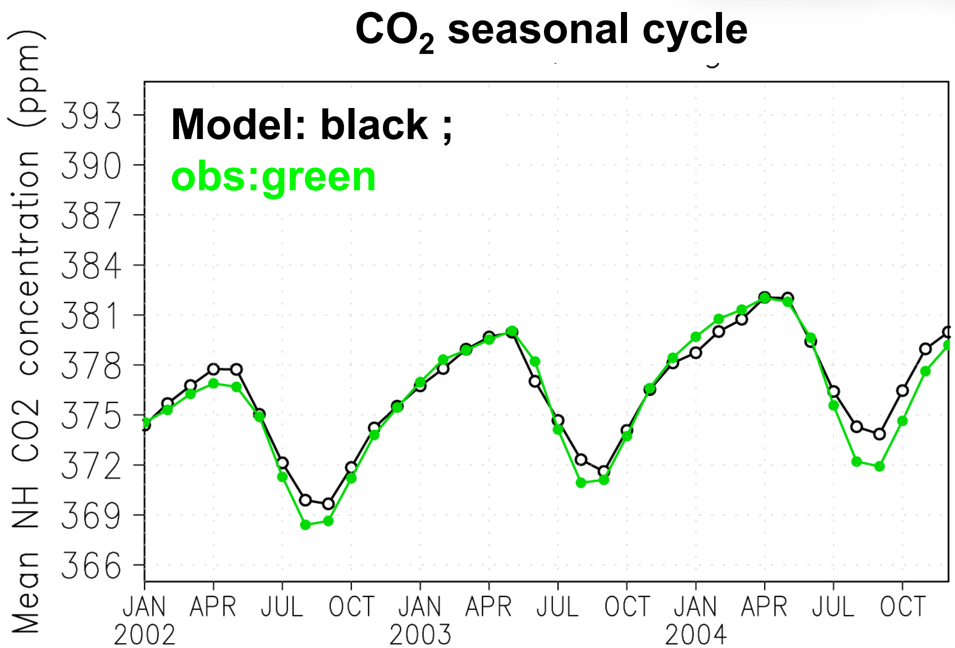
Outline

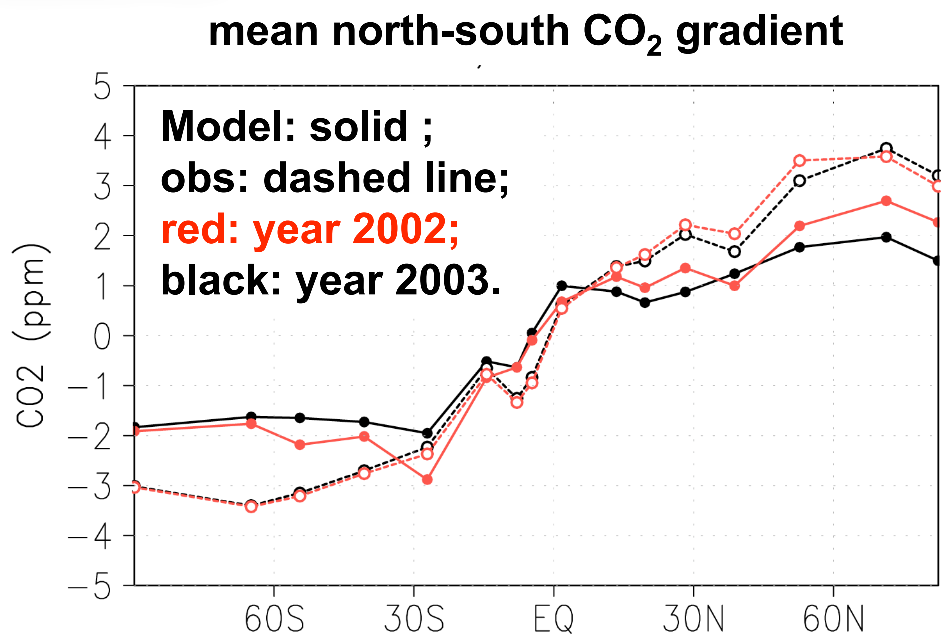
- CO_2 simulation in Community Atmospheric Model 3.5 (CAM 3.5)
- Methods to assimilate AIRS CO_2 with Ensemble Kalman Filter (EnKF)
- Preliminary results
- Summary and future plans

CO_2 simulation in CAM3.5

- Community Atmospheric Model 3.5 (CAM 3.5) coupled with Community Land Model 3.5 (CLM 3.5)
  - Finite Volume dynamical core
  - 2.5°x1.9° horizontal resolution, with 26 vertical levels up to 3.5hPa.
- CO_2 is transported as a tracer in CAM 3.5
- Carbon flux forcing
  - Fossil fuel emission (yearly average value in 2003)
  - Ocean C flux (changes with month; Takahashi et al., 2002)
  - Land C flux (changes with month; CASA annually balanced flux from Transcom 3)
- Four-year model integration started from 01Jan 2000

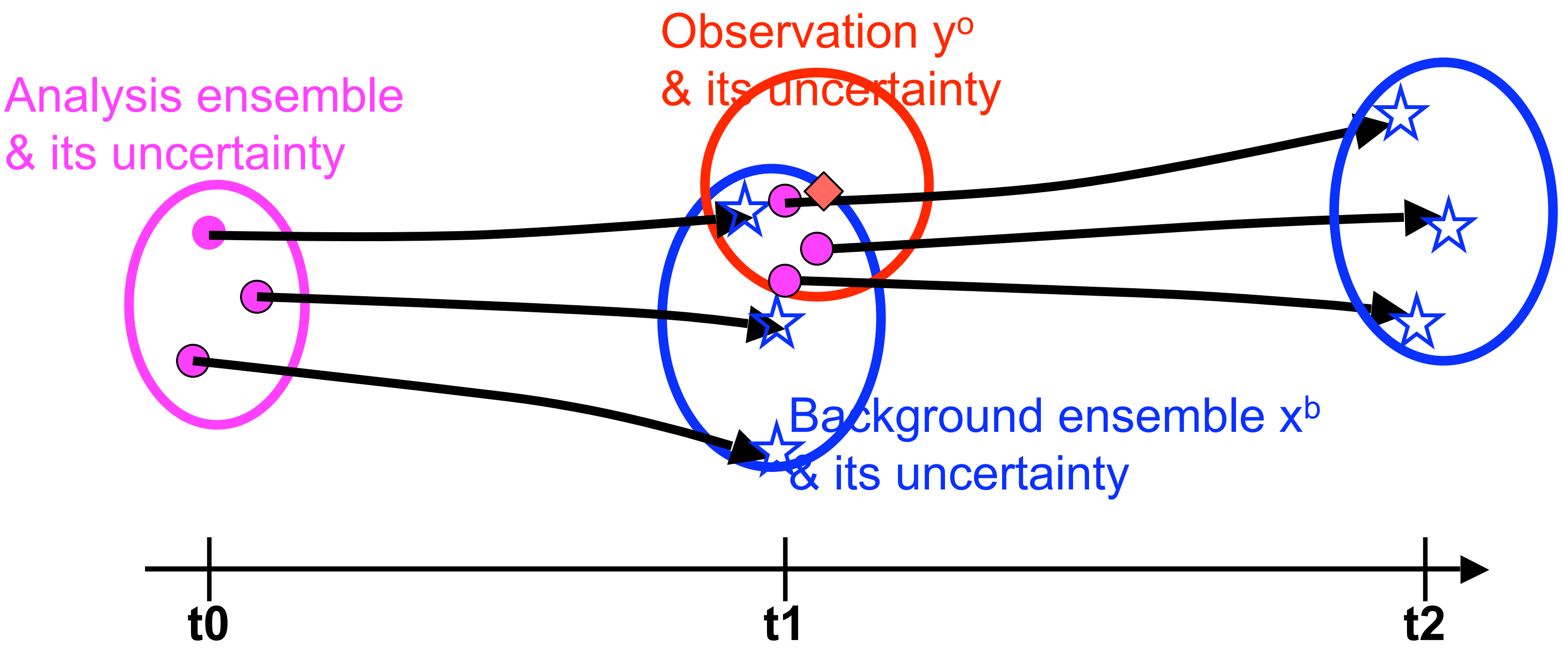
Comparison between model simulation and observations





- Seasonal cycle simulation is pretty good even though the flux is not perfect.
- N-S model gradient is smaller than observations, similar to Engelen at al. 2008.

Ensemble Kalman Filter



✓ Analysis mean $\overline{\mathbf{x}}^a = \overline{\mathbf{x}}^b + \mathbf{K}(\mathbf{y}^o - h(\overline{\mathbf{x}}^b))$, $\mathbf{K}$ is function of background error and observation error.

$h(\cdot)$ is the observation operator, which interpolates model forecast to observation space (more details later);

CO_2 observation operator

- Model forecast x^b is CO_2 vertical profile;
- AIRS CO_2 is weighted column Volume Mixing Ratio (vmr);

=> observation operator: interpolate x^b to obs location & calculate model forecast weighted column CO_2 vmr based on CO_2 profile.

$$\mathbf{y}^b = h(\mathbf{x}^b) = \mathbf{A}^T(\mathbf{Hx}^b) = \sum_{i=1}^{k} a_i (Hx_i^b)$$

$\mathbf{x}^b$: model forecast CO_2 vertical profile;

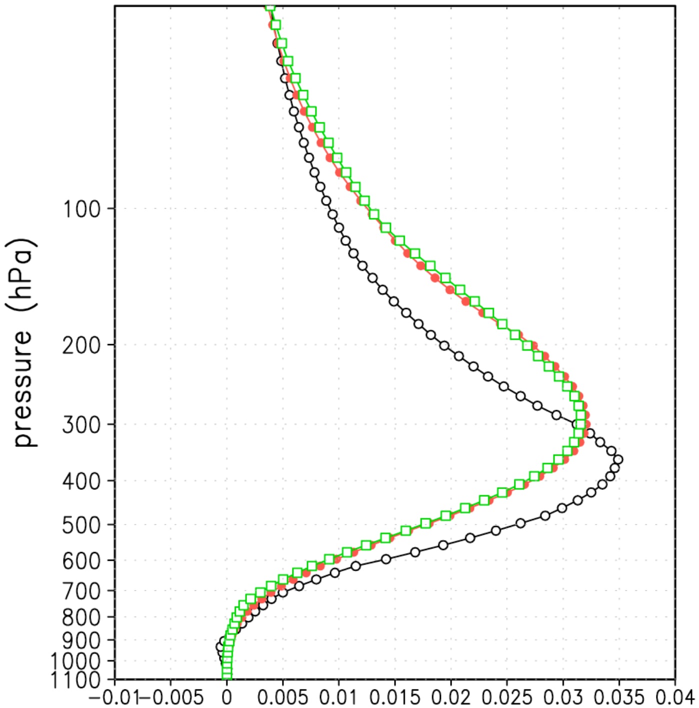
k: the total vertical levels; H: spatial interpolation operator;

$\mathbf{y}^b$: model predicted CO_2 column mixing ratio.

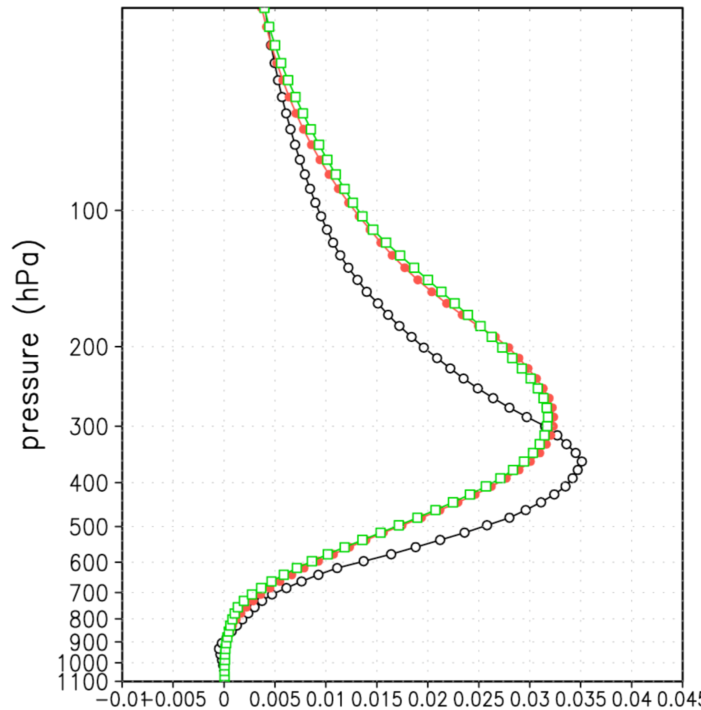
$\mathbf{A}$: averaging kernel; a_i is the element at ith vertical level;

Averaging Kernel

Averaging kernel for 370ppm
(black: 90º; red: 45º; green: 0º)



Averaging kernel for 390ppm
(black: 90º; red: 45º; green: 0º)



1. Interpolate averaging kernels based on $CO_{2(base)}$

$CO_{2(base)}$(time=t)=371.92429+1.840618*(t-t0), where t0=00ZJan1, 2002;

2. Linearly Interpolate among latitudes ;

3. Normalize the interpolated averaging kernels, i.e., sum(A)=1.0

CO_2 assimilation method

- AIRS CO_2 observation is a column weighted value;
- Model forecast CO_2 state $\mathbf{x}^b$ and analysis state $\mathbf{x}^a$ are vertical profiles;

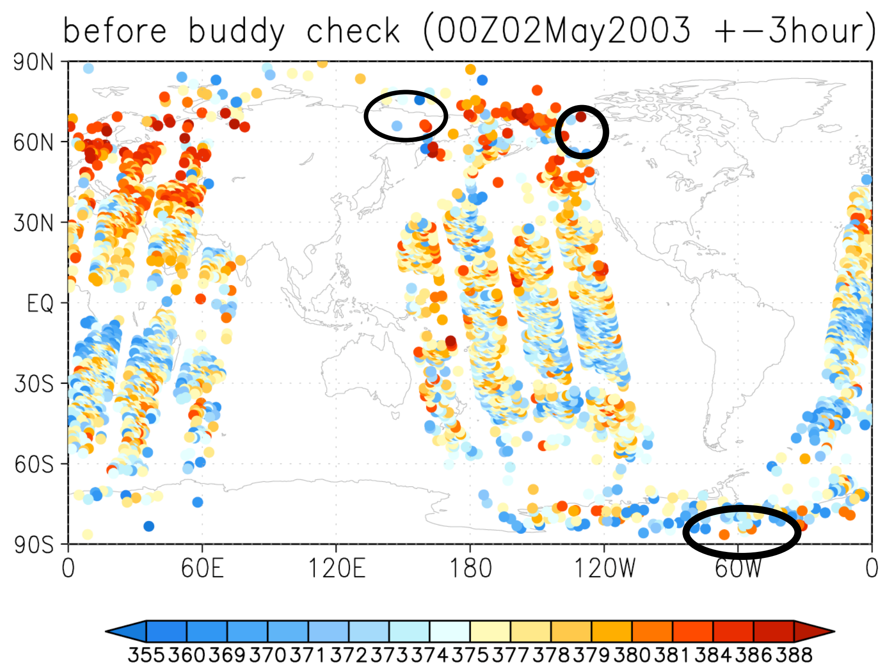
=> How to localize CO_2 column observation to obtain CO_2 vertical profile?

$\Delta y_i^{o\prime} = a_i \times (\mathbf{y}^o - h(\overline{\mathbf{x}}^b));$ localize the column observation increment to i^{th} vertical level by the ith averaging kernel element a_i

$\Delta y_{j,i}^{b\,\prime} = a_i \times h(\mathbf{x}_j^b);$ localize the j^{th} ensemble forecast column CO_2 to the i^{th} vertical level by the i^{th} averaging kernel element a_i

AIRS CO_2 observations

00Z02May, 2003 +-3hour

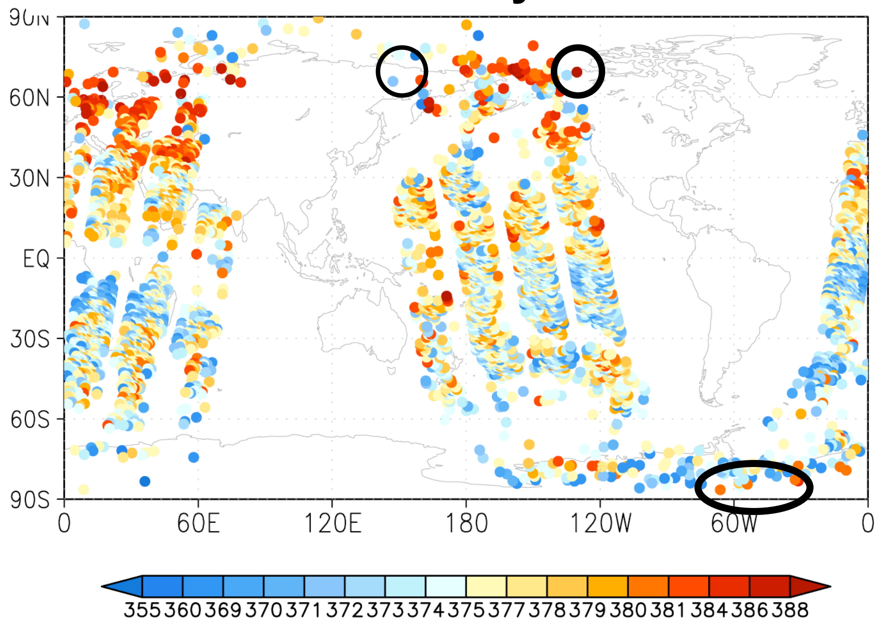


- Some outliers in the AIRS CO2 observations (may not mean bad quality).
- Need some quality control before assimilating these obs.

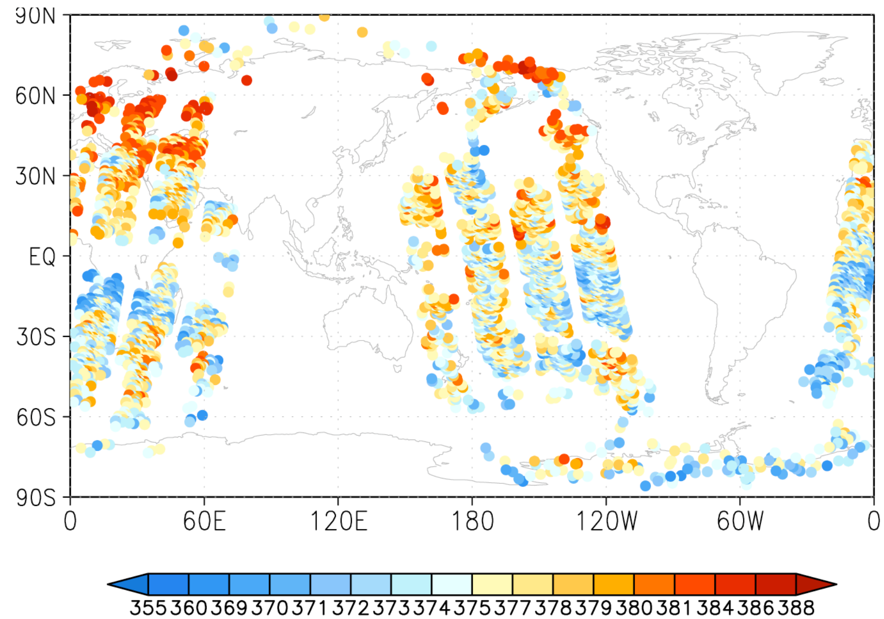
Quality control of AIRS CO2 observations

00Z02May, 2003 +-3hour

Before buddy check



After buddy check

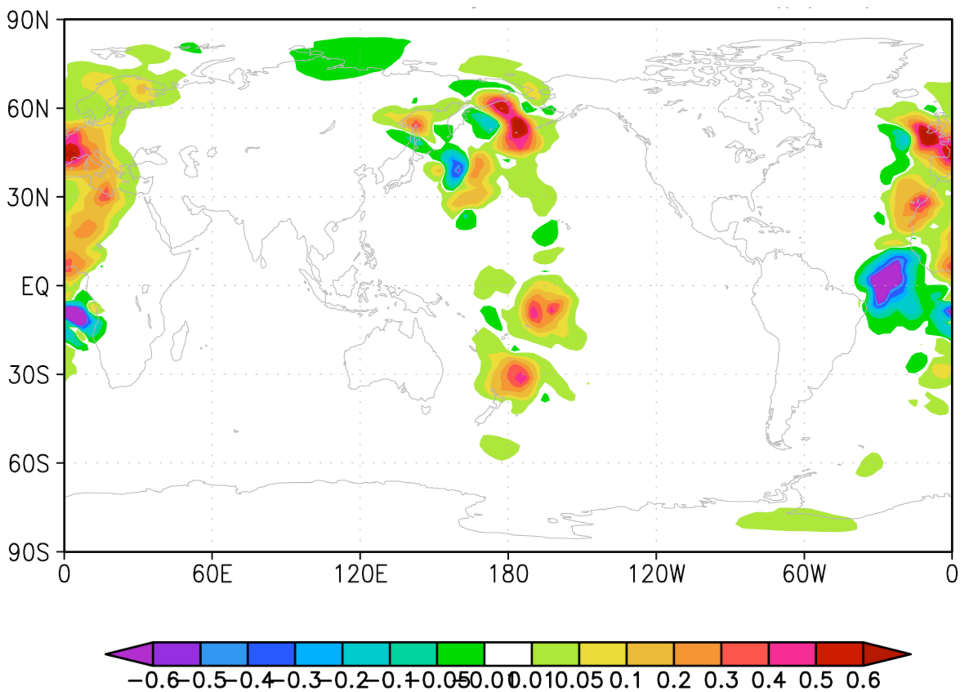


Buddy check: compare each observation to the mean of the observations within 400km.

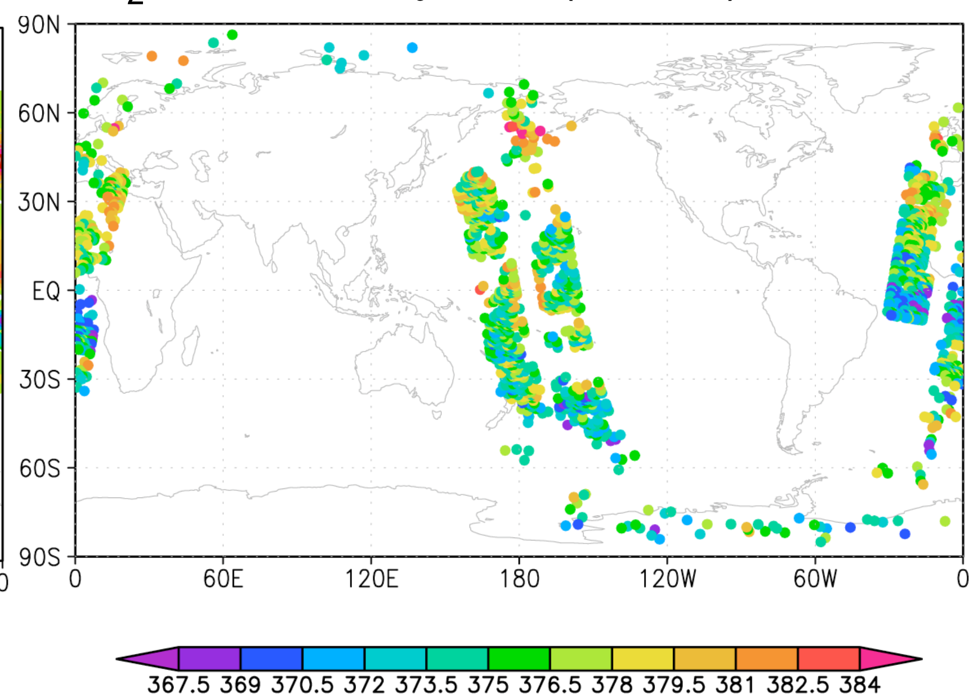
Bad observations: absolute difference larger than 5ppm; filter out about 8%.

Single CO_2 analysis step

350 hPa CO_2 analysis increment (ppm)



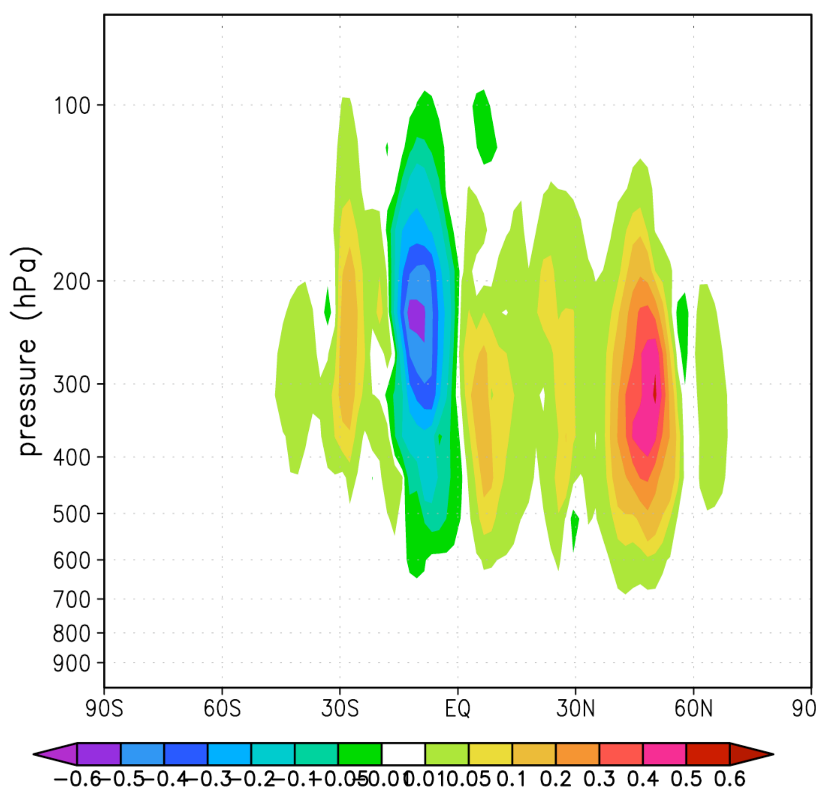
CO_2 at 00Z01May2003 (+3hour) after QC

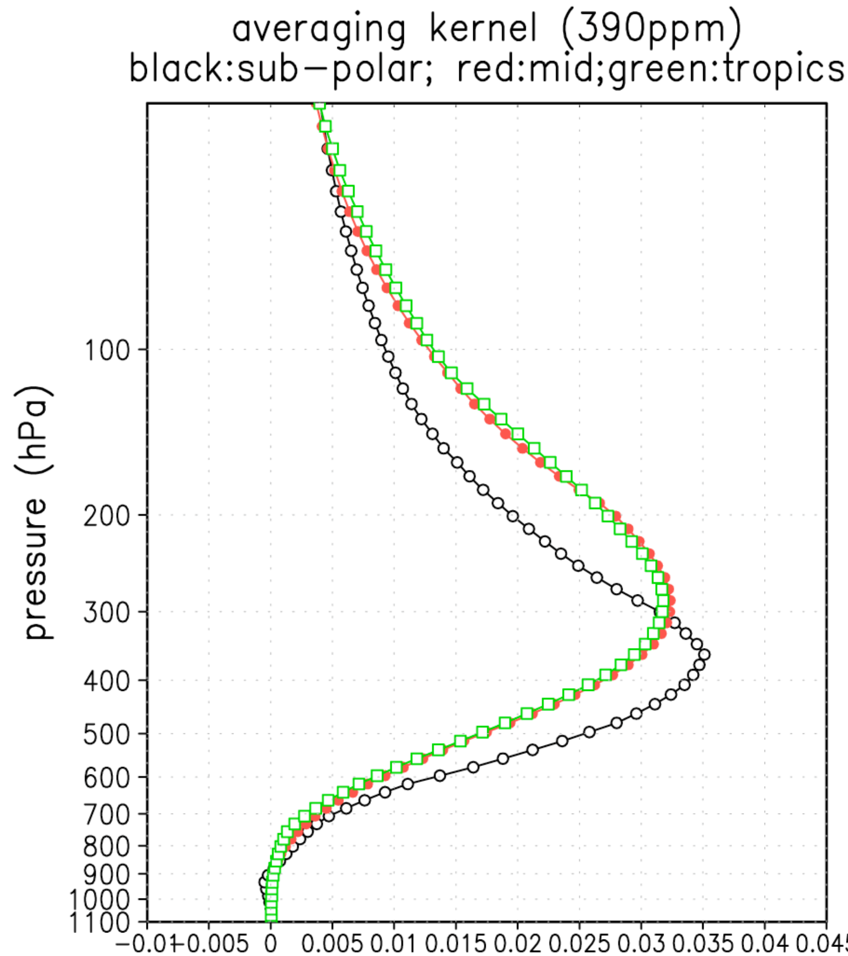


- Analysis increment= analysis-background forecast
- Spatial pattern of analysis increment follows the observation coverage.
- Propagate observation information horizontally.

CO_2 analysis increment vertical profile

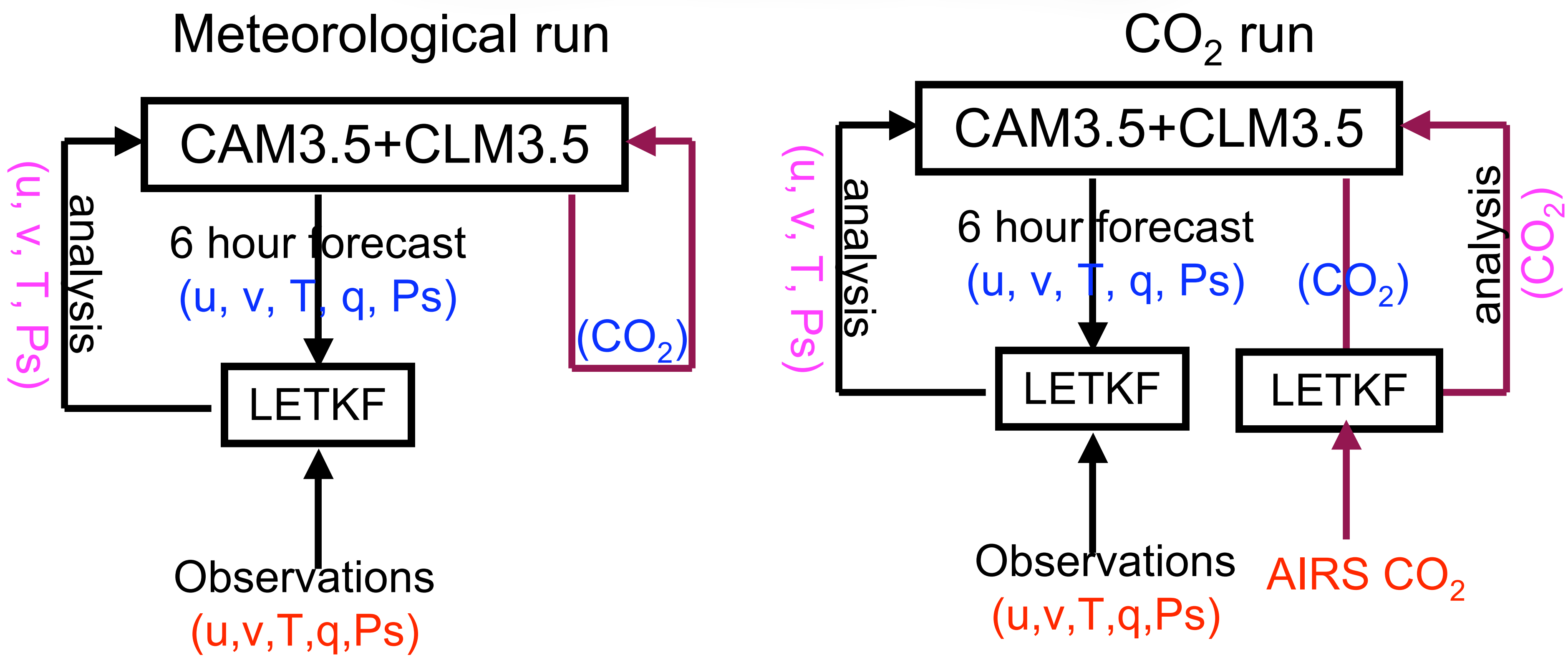
Along 5ºw





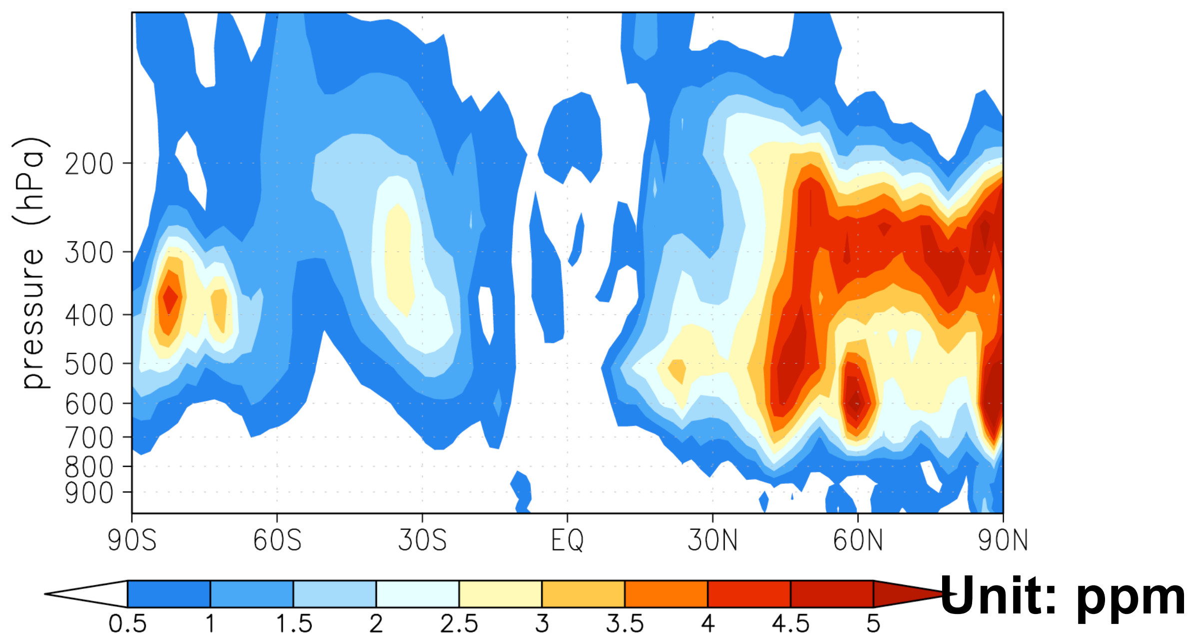
• The magnitude of analysis increments in vertical direction follows the shape of averaging kernel.

Experimental design



- No constraints on CO_2 in meteorological run;
- AIRS CO_2 constrains CO_2 vertical profile in CO_2 run.

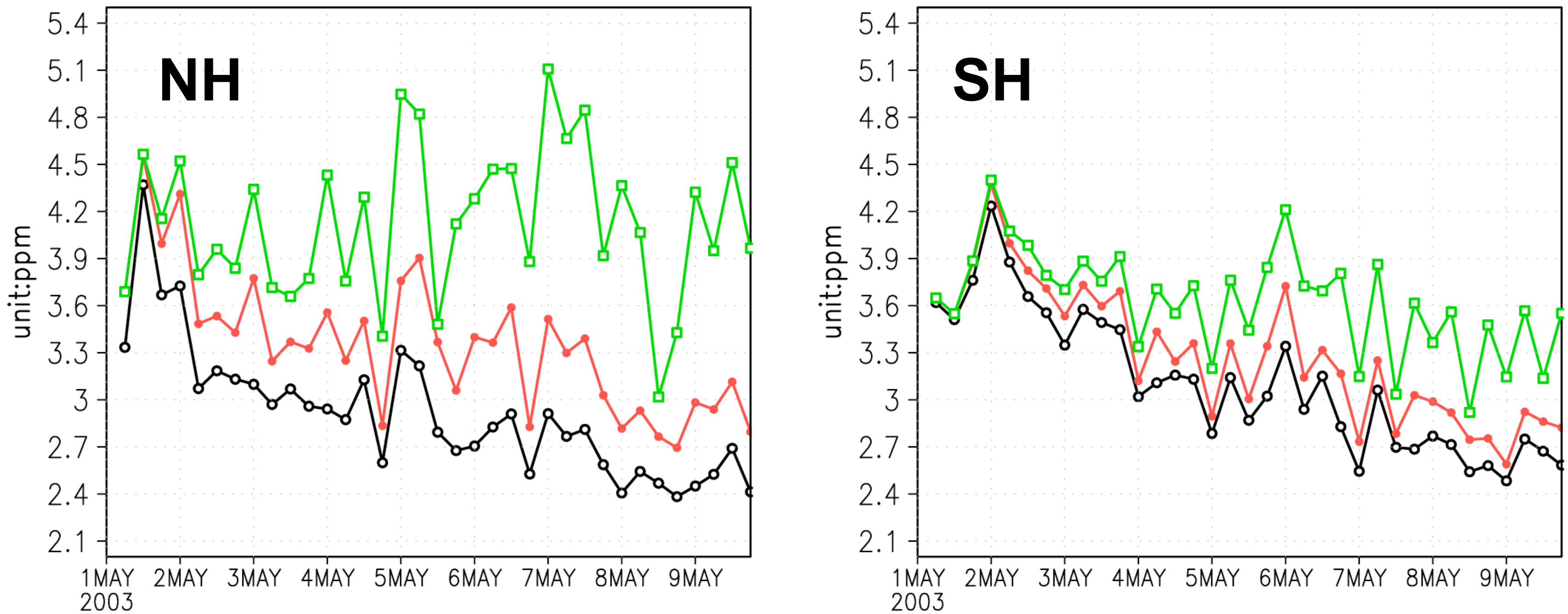
CO_2 difference between CO_2 run and meteorological run



1. Adjustment by AIRS CO_2 spans from 800hPa to 100hPa
2. The adjustment is larger in the NH

Fitting to AIRS CO_2 obs

Green: meteorological run;
Red: 6-hour forecast from CO_2 run; black: analysis from CO_2 run



Fitting to the AIRS CO_2 observations has been much improved in CO_2 run.

Summary

- CO_2 seasonal cycle is well simulated by CAM3.5, but N-S gradient is weaker;
- Proposed a procedure to assimilate AIRS CO_2 retrievals with ensemble Kalman filter;
- Assimilation and transport model propagate the AIRS CO_2 observation in both horizontal and vertical directions.
- As expected, CO_2 column mixing ratio from CO_2 run is closer to AIRS CO_2 retrievals than that from meteorological run.

Future plans

- Extend the length of assimilation and use more accurate averaging kernel.
- Compare the results to in-situ CO_2 observations, e.g., aircraft data.
- Develop more sophisticated QC.
- Explore multivariate CO_2 data assimilation.
- Use carbon flux predicted by the online CASA model.
- Based on the simulated experiments of Ji-Sun Kang (UMD), ultimately, estimate carbon flux based on AIRS CO_2 data and GOSAT CO_2 data